12-2-2011

Utilizing Technology to Increase the Recycled Content of Asphalt Mix Designs

Nicholas Ricketts
nrickett@purdue.edu

PURDUE
UNIVERSITY

Purdue University West Lafayette, Indiana

College of Technology

Utilizing Technology to Increase the Recycled Content of Asphalt Mix Designs

In partial fulfillment of the requirements for the Degree of Master of Science in Technology

A Directed Project Report

By

Nicholas L. Ricketts

November 29. 2011

Committee Member	Approval Signature	Date
Mark Shaurette, Chair **Building Construction**	______________________	________
James Jenkins **Building Construction**	______________________	________
Yi Jiang **Building Construction**	______________________	________

Utilizing Technology to Increase the
Recycled Content of Asphalt Mix Designs

Nicholas L. Ricketts

Purdue University

November 29, 2011

Mark Shaurette, Chair
Building Construction

James Jenkins
Building Construction

Yi Jiang
Building Construction

Acknowledgments

The author wishes to express his deepest appreciation to the members of his graduate committee, Professor Mark Shaurette, Professor James Jenkins, and Professor Yi Jiang, for their help and encouragement in completing this project. I would like to thank my employer, Brooks Construction, and especially John Brooks, William Stevens, Pam Manaloff, Pam Sievers, and Jodie Pollick for their direction, assistance, and participation in collecting and analyzing the data used in this project. I would like to thank John Crowe and Bill Grant from Cyclean Incorporated for their assistance in the explanation of the design and procurement of the new type of asphalt mix that was studied in this project. The completion of this project truly displays the value of teamwork and cooperation.

Table of Contents

Page

List of Figures

List of Tables

Table: **Page**

Abstract

This directed project examined the idea that increasing the amount of recycled asphalt product in road construction will result in a comparable performance to the current levels of recycled asphalt product in today's pavement. A critical review of literature is structured in four areas: describing the need (financial and environmental) for the increased use of recycled materials, describing how others have addressed the issue and technology needed for increasing the use of recycled content, describing how some contractors have created the technology needed, and finally describing the direction needed in order to encourage customers and government agencies to embrace the idea of using asphalt created from a high percentage of recycled materials. Data collection involved actual projects using asphalt with an increased recycled content, comparing the performance and costs to a conventional asphalt mix.

1. Introduction

According to the website of the Georgia Asphalt Pavement Association (GAPA, 2010), much has changed since the nation's first Earth Day in April 1970. Americans are now recycling 28 percent of products in the municipal solid waste stream. For some industrial products, the recycling rate is much higher, and reclaimed asphalt pavement leads all at 80 percent. In fact, the hot mix asphalt industry recycles approximately twice the tonnage of asphalt pavement as the amount of recycled paper, glass, plastic and aluminum combined. In addition to recycling the asphalt pavement, the asphalt industry has also begun to incorporate the use of other materials into the pavement content. These materials include steel slag, crumb rubber, and roofing shingles. The Federal Highway Administration estimates that 100.1 million tons of asphalt pavements are scraped or "milled" off roads during resurfacing and widening projects each year (GAPA, 2010). Of that, 80.3 million tons are reclaimed and reused as part of the nation's roads, roadbeds, shoulders and embankments. For road surfaces, studies have determined that mixes containing 10-25 percent of reclaimed asphalt pavement have performed well in numerous states. Even higher percentages have been used successfully in lower layers (GAPA, 2010). The use of recycled asphalt pavement has grown widely, reducing the use of virgin materials and helping to preserve landfill space as well as reducing the energy required to obtain the virgin materials. State highway agencies and taxpayers benefit from this recycling, as it stretches tax dollars, allowing more roads to be kept in better condition.

Reclaimed asphalt pavement (RAP) is the term given to removed and/or processed materials containing asphalt and aggregates. These materials are generated when asphalt pavements are removed for construction, resurfacing, or to obtain access to buried utilities. When properly crushed and screened, RAP consists of high quality, well graded aggregates coated by asphalt cement. Recycling asphalt pavement makes both environmental and economic sense. Reclaimed asphalt pavement presents a "gold mine" of pre-processed road-building materials, where the value is contained in the aggregates and oil. When asphalt pavement is reused in a new asphalt mix, the old asphalt cement is rejuvenated so that it becomes an active part of the glue that holds the pavement together, just like the old aggregate becomes part of the aggregate content of the new mix. These properties make asphalt a uniquely renewable pavement. When properly processed, the same material can be recycled again and again, never losing its value.

The Hot Mix Asphalt (HMA) industry has been recycling on a large scale since the 1970s Oil Embargo. Research on mix properties and modifications to plant equipment were quickly done in response to the asphalt shortages (caused by the shortages in petroleum) at that time, and within a few years, recycling became a commonplace practice. Over the years, contractors generally stuck with having one stockpile of recycled material and feeding anywhere from 10 to 25 percent RAP into the mix (APAI, 2010). This produced significant cost savings, and the industry was plateaued at this level of recycling because the technology at the time did not allow for a higher percentage of RAP. Contractors and owners did not demand the equipment and technology at the time to take it to a higher level. It is time to consider means for increasing RAP content even further. RAP is a resource rich in asphalt and aggregate, and just as processed virgin materials are tested, the quality of RAP should be judged. This directed project will show the cost advantage of increasing the use of recycled asphalt materials, while maintaining performance, and ultimately creating a sizable financial and competitive advantage for the company that incorporates its use.

1.1 Statement of Problem

Over the past few decades, asphalt contractors have generally maintained one stockpile of recycled asphalt, reclaimed from various road and highway projects. This stockpile of reclaimed asphalt product has been used to make up anywhere from 10% to 25% of any hot-mix asphalt mix design. This produced significant cost savings, and the industry was content to remain at this level of recycling. Over the last few years, however, those cost savings have begun to dry up due to the increasing costs of oil prices, which have dramatically increased the overall cost of asphalt. The cost of oil alone requires the industry to move past the current plateaued levels of recycling.

Over the past few years, the price of asphalt binder, the "glue" in hot mix asphalt, has shot up more than the price of any other road construction material. Between 2005 and 2007, liquid asphalt binder costs more than doubled from about $160 per ton to$360 or even $400 per ton in some areas (Brown, 2007). November 2011 pricing is $482 per ton in Indiana (INDOT, 2011) and $637 per ton in California (CALTRANS, 2011). New technology is available that allows mix designs for pavements to contain up to 40% or more of recycled asphalt by weight. These mixes are usually used below the surface layer. Allowing more recycled content in these subsurface layers will allow the contractor to maintain two or three recycled-asphalt stockpiles, each with different characteristics and aggregate sizes, giving the contractor greater flexibility in creating mix designs for specific applications. This project will show how new technology in creating asphalt mixes allows for increasing the use of RAP, while maintaining the required performance. The current use of reclaimed asphalt pavement in hot-mix asphalt is not being used to the full potential that technology will allow.

1.2 Significance of Problem

Roads and highways are an extremely important part of the U.S. economy. Products and goods produced by manufacturing and service facilities must be shipped to customers. The creation and maintenance of those roads are important to the survival of the infrastructure that allows the transportation of people, food, and goods to almost anywhere that is desired. Unfortunately, U.S. paved roads are wearing out faster than they can be repaired or replaced. With normal use, road surfaces are restored at varying intervals, which costs substantial sums of money. As highway costs mount, highway engineers and administrators must look for ways to extend the life of the roads and/or find newer, cheaper ways to construct and maintain them. The basic ingredients of blacktop pavement, asphalt and durable, skid-resistant aggregate, are becoming increasingly scarce just when they are needed most (Bernard, 1985).

Recycled asphalt pavement (RAP) is a resource rich in asphalt in aggregate, and just as we test and process virgin materials, so too should we judge the quality of RAP and process it (Newcomb, 2006). The desire to use recycled materials is there. Producers want to do it because it is more economical than virgin materials, and governments want it used because it is good for the environment, as well as cheaper. Most asphalt producing plants have learned how to handle the recycled material differently, utilizing the most out of the material. The increasing use of RAP posed some new problems in the processing and production of hot-mix asphalt. Some of the processes and methods that needed to be considered included reclaiming through milling and full-depth removal; processing through milling, grinding and crushing; storage; mix designs; and processing in a hot-mix facility (Banasiak, 1997). As solutions to these problems were found, and perfected, new technologies have come into existence. High recycled asphalt content mixes may pose special problems in terms of workability and compactability (Newcomb, 2008). In these cases, engineers and producers are working on additives and rejuvenators in order to overcome this issue. Since 1992, a company located in California, called Cyclean, has been working on alternative, cleaner ways of creating new asphalt from recycled asphalt. Using microwave heaters, instead of propane burners, and a petroleum-based rejuvenating oil, they have been able to create asphalt pavement using 100% recycled product, while eliminating the air pollution normally associated with the production of asphalt. In doing so, over the course of five years they have prevented nearly one million tons of asphalt from entering the local landfills (Martin, 1992). Several asphalt makers have made the step to creating a better recycled product. Thus the new technologies and procedures being created and tested may in turn create a new market for those who have made that step.

1.3 Statement of Purpose

Researching the technology available, the purpose of this directed project is to provide a professional guideline to highway engineers identifying the benefits of the cost and quality that an increased RAP mix design for asphalt has to offer. The objectives for this project are:

- To investigate the process involved in reclaiming asphalt and then using it again.
- To analyze and compare the cost of producing conventional asphalt against asphalt containing higher amounts of recycled material.
- To assess the cost savings achieved through the use of high RAP asphalt.

2. Review of Literature

The hot-mix asphalt (HMA) industry estimates that over 93% of the paved roads in the United States are paved with asphalt (Johnson, 2008). For the variety of road builders who make a “habit” of using asphalt, there are several reasons for doing so. Items such as ease of construction and upgrading, ease of trenching and repair, low cost, smoothness of ride, better visibility of striping, recyclability and environmental friendliness have allowed the use of asphalt to increase year after year (Smith, 1998). Two of those items in particular, recyclability and low cost, have a very direct relationship with each other.

2.1 Cost Background

It is a general consensus that the hot-mix industry has been recycling on a large scale since the 1970s. Research on mix properties and modifications to plant equipment were quickly done in response to the asphalt shortages experiences at that time (Newcomb, 2006). Engineers, as well as the contractors, knew that for costs to stay down and bids to be competitive, there needed to be a way to incorporate the use of existing, ground up asphalt pavement into the mix of a new pavement to be installed. Here, the existing pavement represents a resource rich in asphalt and aggregate. According to the Asphalt Alliance, the use of recycled asphalt pavement has grown widely, reducing the use of virgin materials and helping to preserve landfill space. Highway agencies and taxpayers benefit because recycling stretches tax dollars, allowing more roads to be kept in better condition. The Georgia Asphalt Pavement Association (GAPA) feels the life-cycle costs for asphalt are better than any other pavement. Compared to concrete pavement, asphalt pavement offers lower initial construction costs, less maintenance over the life of the pavement, and then when repairs are needed the pavement can be over-laid instead of completely removed such as is with concrete pavement.

2.2 Environmental Background

Perhaps just as important as the universal cost issues that affect us all regarding the construction of the roads and highways are the energy and environmental issues that using recycled asphalt in our pavements allows us to tackle. According to the leading industry website *asphaltroads.org*, from the production and placement of the pavement on the road through rehabilitation with recycling, asphalt pavements minimize impact on the environment. Asphalt pavements require about 20% less energy to produce and construct than other pavements. They are faster to construct and fix, which means the pavement can be opened to traffic much sooner than with concrete pavement. Overall, lower consumption of energy for production and construction, lower emissions of greenhouse gases, and conservation of natural resources help make the case for the use of asphalt.

2.3 The Need for Increasing the Use of Recycled Product

Some local and state governments have already conceded that the use asphalt pavement has helped to save construction and maintenance costs of their roads and highways, as compared to concrete. Some cities and counties are choosing to restore street surfaces with recycled asphalt rather than new pavement. When it is no longer cost efficient to cover damaged pavement with layers of new pavement, the full depth recycling of the asphalt will still cut waste and lower costs (Ayers, 1994). The Federal Highway Administration has tackled the issue of increasing the use of recycled asphalt product (RAP) into their mix design requirements. Before the green light could be given to the increase rate of RAP, many questions had to be answered (Bernard, 1985). These questions included: How can the recycling potential of existing pavement be evaluated? How much virgin aggregate and asphalt should be added to the recycled mix? Are rejuvenating agents required to restore "life" to the weathered asphalt and, if so, what types and amounts? What are the relative merits of hot and cold recycling and when is each appropriate? How is construction quality control to be conducted? In the 1980s, local, state, and federal governments undertook a series extended research projects to answer these questions, and the results were used to develop the current recycling methods in use today (Bernard, 1985). Asphalt recycling is still using standards created in the 1980s.

Asphalt technologists agree that increasing recycled content is one of the most effective ways to lower hot-mix costs (Brown, 2007). The technology exists to create pavements and mix designs that contain up to 40% or more of recycled asphalt by weight. Usually, those mixes are contained in the layers below the surface layer. Although some government agencies have begun to use recycled asphalt, there are a significant number of state and local agencies that still do not permit the use of recycled pavement. Many state and materials engineers may believe recycled materials are inferior to virgin materials, or they may just not have enough experience with the recycled product. Unfortunately, as this new technology breaks through its infancy, there will be bad experiences with bad contractors. For those cities and counties that have experimented with recycling techniques, they are discovering that the use of recycled materials can increase road performance and save money, both up front, and over the life of the road (Parks, 1993).

2.4 Experimenting

Faced with the problem of what to do with all the old asphalt, the city of Los Angeles turned to a new recycling technology, created by Cyclean, which not only saved the city more than $1 million, but also cut air pollution. Cyclean's process recycled the pavement 100%, while meeting pollution restrictions and was equivalent in performance standards to new asphalt. The project also cost the city of Los Angeles about 30% less than it was paying for virgin hot mix asphalt materials, kept 200,000 tons of asphalt and concrete out of local landfills and saved the mining of 180,000 tons of rock and 60,000 barrels of oil (Parks, 1993). While addressing the issue of using recycled product in new asphalt, engineers have been able to devise ways in which asphalt that is milled from a highway project and how it is transported to a new plant that handles recycled asphalt material. There it goes through gradation control, computer-monitored mixing and heating and moisture removal. After this process, the recycled product is mixed with a chemical rejuvenator that restores the viscosity of the asphalt.

Asphalt consists of two main fractions – asphaltenes, which are the hard brittle component, insoluble and not affected by oxidation and the highly reactive sub-fractions called maltenes, which are oily and resinous in appearance. The relationship of maltene and asphaltene percentages become out of balance during the aging and oxidation process. The asphalt rejuvenator is a manufactured product which has the ability to absorb or penetrate into the pavement and restore those reactive components that have been lost due to oxidation. Cyclean's process can also take below-standard RAP, recycle it, and produce a higher quality product that it was before.

In the city of Los Angeles, experience has shown success in experimenting with using recycled asphalt and Cyclean's technology. When the facility was only five years old, it was recycling nearly 1 million tons of asphalt taken from city streets, most of which would otherwise have ended up in landfills. Other municipalities and agencies, such as the California Department of Transportation, have recycled asphalt using different technologies. But Cyclean's process allows the city to pave with 100% recycled asphalt while other processes allow only up to 60% recycled material to be used (Martin, 1992). Figure 1, shown below, describes some of the successes experienced by the city of Los Angeles through Cyclean's technology.

Figure 1. *Letter from Bureau of Street Services, Los Angeles, CA to Cyclean.*

Dear John:

I am pleased to write in regards to your request that I describe the relationship between Cyclean of Los Angeles, LLC and the City of Los Angeles for processing Reclaimed Asphalt Pavement into Recycled Asphalt Concrete.

The City has long been committed to the environmental benefits of recycling and reduced emissions, and are equally determined to maximize the cost-effectiveness of our street paving budget and the quality and durability of the paving materials used on our public streets.

Over the past nine years, I have carefully watched the progress of Cyclean's cooperative efforts with the City to establish a low-emission process that efficiently produces hot mix asphalt with greater than 85 percent recycled content. It has been a long and sometimes arduous path, but today Cyclean is meeting the City's quality specifications at a price that is competitive with the prevailing virgin mix commercial pricing structure in Los Angeles.

I project that the contact we have recently consummated will save the Department of Public Works at least $600,000 per year over the costs of purchasing comparable volumes of virgin hot mix asphalt. Although we have extensively investigated alternative technologies and approaches for high recycled content asphalt pavement, none have achieved results comparable with Cyclean's process.

I believe other municipalities would be well served by the Cyclean process.

Sincerely,

GREGORY L. SCOTT, Director
Bureau of Street Maintenance

After several years of research and observations, the city's Bureau of Street Services decided to move ahead with upgrading their own asphalt plants and have now become the only municipality in the United States which utilizes 50% of recycled asphalt pavement (RAP) in new asphalt concrete mixtures. Over the years, this has resulted in millions of dollars of savings by reduction of the cost of resurfacing projects by reducing the cost of fresh aggregates, binders and need for additional materials being dumped at the landfills (Los Angeles Bureau of Street Services, 2011).

Recycling and reusing 100% of the reclaimed asphalt pavement without adding any virgin materials is a challenging task. The reclaimed asphalt material must be carefully processed and screened in order to be used in high RAP percentage asphalt. The RAP material needs to be evaluated before the actual mix design. This is because with aging and oxidation certain significant changes occur in the HMA. For the binder, this includes loss of the lighter fractions and a corresponding increase in the proportions of the asphaltenes, hardening (increase in viscosity), and loss of ductility. The gradation of the aggregate may change due to degradation caused by traffic loads and the environment. Hence the composition of the RAP must be determined at the beginning. Most agencies determine aggregate gradation, asphalt content, and asphalt viscosity at 60°C for the reclaimed asphalt pavement. The aged asphalt binder must be extracted from a representative sample of the RAP to determine these properties (FHWA, 1997).

Most of the present RAP recycling technology is limited to use the 20%-30% RAP as a maximum content for the wearing courses (surface course) of asphalt pavements (Huh and Park, 2009). One of the main goals on the large end, as Cyclean has been able to achieve, is focused on restoring original properties of the straight asphalt pavement mixtures by using rejuvenators. Once achieved, the maximum use of RAP, along with excellent quality, simple processes and competitive prices will make this technology very attractive. Fortunately, the high percentage use of RAP in the base and intermediate layers of asphalt has been met with high willingness to use by most entities. However, people are reluctant to use a high percentage in surface layers because of early development of mix designs and the potential for cracks. The aging of existing asphalt causes it to stiffen. Asphalt engineers who want to reuse asphalt from previous pavements in their new pavements usually add a softer binder, or intermediate layer to compensate for the harder asphalt that comes with the aged, recycled pavement (Zeyher, 2009).

Brooks Construction Company, Inc., a medium size asphalt contractor located in northeast Indiana, has proceeded to continue experimenting with the process that Cyclean had begun. In the summer of 2010, they committed to building a new plant to be used exclusively for producing a very high-RAP asphalt product. During the 2011 season, they experimented with several mix designs, and intend to begin producing and applying the product to a variety of projects.

As stated previously, recycled asphalt pavements have been in service for many years. The problem, as many will state, is the lack of well-documented field performance studies. Any engineer or scientist will acknowledge the discrepancies that can arise when comparing laboratory based results to field based performance. As part of a study for the California Department of Transportation (Caltrans), Stantec Consulting has investigated the recycled pavement performance of actual projects across a variety of climate conditions ranging from the desert to the mountains as well as the coastline. Stantec Consulting used a comprehensive evaluation program that covered the structural performance index (SAI), the roughness index (RI), the distress index (DI), and the construction consistency index (CCI).

The SAI value pertains to a segment's ability to carry heavy loads. A special piece of testing equipment, called a Dynaflect, is used to determine the SAI. The Dynaflect measures deflection at varying distances from a test point to determine the stiffness of the pavement section; the stiffer the pavement, the stronger the section. The roughness index (RI), used in conjunction with the riding comfort index, measures and records the longitudinal roughness of pavements based on International Roughness Index (IRI) standards in an objective fashion. While traversing a pavement, profile elevations are collected at one foot spacing. This data is subjected to a vehicular displacement simulation to determine the pavement roughness (RI). This data is summarized at 100 ft. intervals and then correlated to an assessment of ride quality as determined by the ratings of a group of representative users of the pavements. This assessment of ride quality is termed the Riding Comfort Index (RCI). These roughness measurements therefore provide a rapid, objective, repeatable means of estimating the subjective RI ratings of the traveling public.

The distress index (DI) is determined by actual surface conditions on the road. The value considers the amount and type of distress, average area, and severity of the distress for each section of the network. The construction consistency index (CCI) of a RAP pavement is a common concern, since it involves the very physical qualities of the asphalt before it is ever laid. Based on the climatic sections considered for their research, the long-term performance of RAP sections along the coastline performed better than expected (Zaghloul, Holland, & Peng, 2007). In analyzing the results of their research, I will seek to determine if the recycled pavement performed in a comparable way to other materials subject to the same conditions.

Cyclean's research has shown promising results with the use of recycled asphalt in new pavements. For those who are still reluctant to embrace the possibilities that using RAP has to offer, other options for using the recycled product in other, less important areas are available. For a project in Missouri, engineers decided to use the recycled asphalt product in the reconstruction of the shoulder and subgrade along a state highway. Using full depth reclamation (FDR), the full asphalt pavement section as well as a portion of the underlying subgrade are pulverized and blended to provide an upgraded, homogeneous base course, which then can be treated chemically to provide a much stronger, stiffer, and longer-lasting layer for the new pavement (Ryan, 2010). Existing asphalt pavement is a very renewable resource. Cost savings and environmental savings are very attractive to the contractors and government agencies alike. Using recycled pavement has a direct impact on the saving of the cost of liquid oil needed for paving and it supplies resources that are becoming scarce (Johnson, 2008).

2.5 Creating and Designing

A mix design incorporating RAP, just like any other mix design, should be carefully developed, taking into account the job specifications, available materials and economics. Proper testing begins with a representative sampling of the stockpiles of RAP. It can't be emphasized strongly enough that proper sampling techniques must be used to obtain RAP samples for analysis (Decker, 1999). The conduct of study and collection strategies for the creation and production of a high-RAP design mix is similar to those of normal mix designs. It's important to make sure that comparisons are made on an apple-to-apple basis.

Even if a road can't stay flawless forever, it doesn't have to go to waste. Crumbled pavement is often scooped up, crushed, and recycled into new paving material or other highway structures (Wu, 1998). This saves the consumer millions of dollars every year. As obvious as it may seem, asphalt pavement is scientifically proportioned, with sand, aggregate, and liquid asphalt. Utilizing current technology to help us maximize the use of recycled product is a win-win for the contractor and the consumer.

3. Procedures

3.1 Assumptions

It is assumed that the total tonnage of the quantity of reclaimed asphalt stored in plant yards and stock piles will continue to rise with each year of road construction. Along with this increase, the availability of virgin materials needed for asphalt construction will continue to decrease. Since the RAP % will remain steady, and due to this shortage of virgin materials and increased demand, their prices will continue to increase, as will the cost of oil and petroleum based products. Government agencies and private owners will prefer to purchase cost effective products, while maintaining performance standards. Due to their unique properties, recycled materials will need to be handled differently at the asphalt plant than handling procedures for normal aggregate.

3.2 Delimitations

In order to maintain direct control over the design and application of the alternative asphalt mix, this study will focus only on those jobs performed directly by Brooks Construction Company. To maintain manageability of collected data, this study will focus on the financial data related to cost savings plus fees while using the alternative asphalt versus the standard design. In order to maintain direct comparisons with each asphalt design, plant and gravel expenses will be included when figuring out total costs.

3.3 Limitations

Due to the time restrictions of this research project, data directly related to the production and application of the alternative asphalt design will only be available during the spring, summer, and fall seasons of 2011. Due to the size of the sample and the labor/equipment requirements of various contractors, specific financial data may not be generalizable to every asphalt contractor. Also, because the infancy of the technology regarding recycled asphalt, some highway engineers may still be unwilling to consider the use of alternative asphalt designs, different from the standard that has been used for years.

3.4 Methodology

The collection of data for this study will be based upon the various projects as secured by Brooks Construction Company, Inc. In the spring of 2011, Brooks Construction implemented the use of high-RAP design mixes into various projects, testing different formulas in order to achieve specific results. Data collection began at the asphalt plant. The stockpiles of recycled materials and the plant costs incurred in producing and storing these materials, and then implementing these materials into the mixing drums were measured and accounted. While at the plant, the costs associated with the chemicals and liquid asphalt needed to produce the high-RAP mix were tallied. After production, data analyzing the transportation and installation of the mix, including equipment and labor was monitored to compare to the transportation and installation of a conventional mix. Finally, the performance of the final product was tested and monitored to confirm adherence to specifications.

3.5 Framework

The theoretical framework will be quantitative in nature, utilizing the case study approach to research. The theory in this study is that use of high-RAP mix designs in asphalt pavements will lead to cost savings while maintaining the desired performance. A bonus being the positive environmental impact it will have. Figure 2 shows the basic framework impacting the cost effectiveness of utilizing high-RAP mixes. These same variables can be used to measure the costs associated with standard mixes.

Figure 2. *Framework of variables affecting cost effectiveness.*

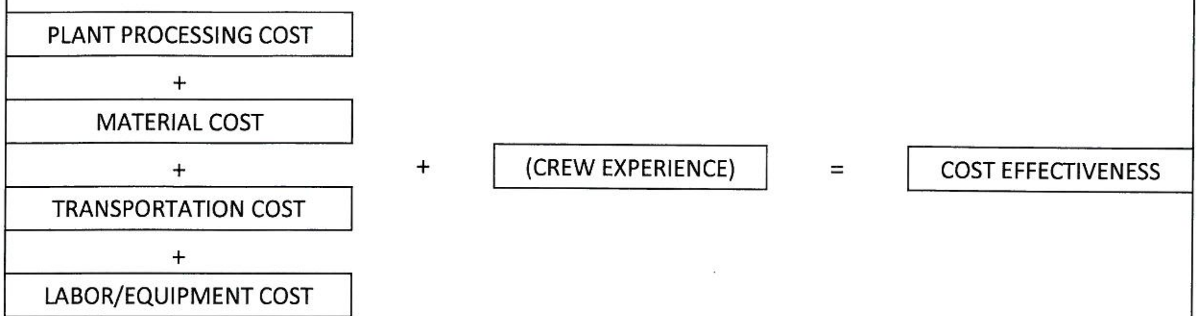


Figure 1. Basic industry items used in the calculation of overall costs. Lowering any of the costs shown on the left will still be dependent upon the crew experience installing the product before determining the cost effectiveness.

This framework was designed in conjunction with the president of Brooks Construction Company, showing the major steps towards the final conclusion. Several smaller variables such as permit fees, testing costs and project monitoring can occur, but are negligible in nature. Only these will be monitored for this study.

Working with Brooks Construction, three major subjects were identified:

1. recycled material is plentiful,
2. recycled material is less expensive than virgin material, and
3. the production of the high-RAP mix is less expensive.

These three issues were identified in studies regarding the handling of the mix by Decker (1999) and the production and use of a high-RAP mix by Martin (1992).

3.6 Procedure Design and Participants

This study consisted of spreadsheets demonstrating the direct relationship between materials and cost. It also consisted of performance analysis sheets that compared the test results of the high-RAP mixes to standard mixes. There were seventeen participants included in the research. It included the persons from the asphalt plant, the drivers that transported the material, the crew that installed the pavement and the office personnel tracking costs. Pam Manoloff, who is the Systems Development and Accounting Manager for Brooks Construction, talked about some specific projects performed by Brooks Construction in 2011 for the Indiana Department of Transportation, and then analyzed the material costs for those projects. Pam Sievers, who is the Quality Control Manager for Brooks Construction, discussed the specifics of what is contained in an asphalt mix design and what the specifications of certain mix designs need to be.

Data collection began at the asphalt plants. Examples of tables used in the analysis of the data are shown below. Table 1 shows the high-RAP design and the total production cost per ton. The Viplex 50 is the rejuvenator used in place of liquid asphalt. Table 2 shows a standard design, which included a considerable less amount of RAP, 20.4% compared to 89.5%. It also contained considerable larger amount of miscellaneous aggregates, 75% compared to 10%. Instead of a rejuvenator, it contained PG 64-22, which is the liquid asphalt. This showed how a larger RAP percentage and lower aggregate percentage can save a considerable amount of cost.

Table 1

Table Display of Construction Costs of High RAP Asphalt Mix Designs

	Unit Cost / Ton	% of Mix / Ton	
Viplex 50 (Rejuvenator)	$ 1,950.00	0.50%	$ 9.75
RAP	$ 0	89.50%	$ 0
Misc Aggregate	$ 15.00	10.00%	$ 1.50
Material Total			**$ 11.25**
Plant Expense (including labor)			$ 9.50
RAP Processing	$ 4.32	89.50%	$ 3.87
License/Technology Fee			$ 7.00
Total			**$ 31.62**

Note. Misc. aggregate includes items such as natural sand, steel slag, limestone, and slag sand.

Table 2

Table Display of Construction Costs of Standard Asphalt Mix Designs

Slag-RAP Surface

	Unit Cost / Ton	% of Mix / Ton	
PG 64-22 (Asphalt Oil)	$ 500.00	4.60%	$ 23.00
RAP	$ 0	20.40%	$ 0
Natural Sand	$ 5.00	20.00%	$ 1.00
#11 Steel Slag	$ 16.00	10.00%	$ 1.60
#11 Limestone	$ 15.00	25.00%	$ 3.75
Slag Sand	$ 5.00	20.00%	$ 1.00
Material Total			**$ 30.35**
Plant Expense			$ 7.00
Total			**$ 37.35**

This procedure is designed to be representative of all asphalt plants. Although the new recycling plant is a new venture, meaning there are no other facilities like it in the United States, it will run all common types of asphalt mixes, thereby creating common samples representative of the general population of asphalt mix plants. After comparison of the material spreadsheets, analysis began on the project management reports showing mix descriptions, cost per ton, plant expenses, technology fees, total mix costs and then a direct comparison between a typical project costs vs. a high-RAP project cost.

4. Findings

4.1 Mix Design Aggregate Comparison

Standard asphalt mix designs contain an asphaltic liquid along with a specific recipe of miscellaneous aggregates. These aggregates normally contain percentages of sand, #5 limestone, #8 limestone, #11 limestone and/or a percentage of recycled material. The aggregates and percentages depend on the type of asphalt being produced. Surface mix designs are going to contain higher percentages of smaller aggregates and base mix designs are going to contain higher percentages of the larger aggregates. Regardless of the type of asphalt being produced, virgin limestone is required. A high-RAP mix design developed by Brooks Construction has allowed for the complete removal of virgin aggregate materials. This mix design, called HyRAP, is made up of completely recycled asphalt, along with a rejuvenator liquid.

Table 3, shown below, shows a comparison between typical mix designs and the new, HyRAP mix designs. Due to company privacy, the specific percentages of typical mix designs have been removed; however the percentage of RAP can be shown as 100% in the HyRAP mix designs.

Table 3.					Asphaltic Cement	Rejuve - nator	RAP	SAND	#5	#8	#11
TYPICAL vs. HyRAP MIX DESIGN				**LOSS FACTOR**	0	0	**8%**	**8%**	**8%**	**8%**	**8%**
*Adjusted by 8% material loss factor				**STANDARD COST**	$450.00	$2,000.00	$6.00	$6.00	$12.00	$13.00	$14.00
mix description	**$ / ton***	**Plant Expense**	**Tech Fee**	**total mix cost**	**LIQUID**		**RAP**	**MISC AGGS**			
SURFACE	$30.19	$8.00	$0.00	$38.19	**4.6%**		**RAP%**	**sand%**			**#11%**
INTERMEDIATE	$26.00	$8.00	$0.00	$34.00	**3.2%**		**RAP%**		**#5%**	**#8%**	
BASE	$24.67	$8.00	$0.00	$32.67	**3.1%**		**RAP%**	**sand%**	**#5%**	**#8%**	
HYRAP SURFACE	$14.66	$11.00	$8.00	$33.66		**0.41%**	**100.00%**				
HYRAP INTERMEDIATE	$14.66	$11.00	$4.00	$29.66		**0.41%**	**100.00%**				
HYRAP BASE	$14.66	$11.00	$4.00	$29.66		**0.41%**	**100.00%**				

4.2 Mix Design Cost Comparison

It's important to also notice the differences in the liquid comparisons. The rejuvenating liquid is very expensive, however percentage wise one can see that it makes up much less of the mix design than the asphaltic cement does for a standard mix. Since each layer of asphalt requires different sizes of aggregate, recycled or not, the savings will differ depending on the mix designs. Table 4, shown below, summarizes the pricing between the standard mix designs and the new, HyRAP mix designs.

Table 4.
Summarization of Pricing

BASE	$32.67
HYRAP BASE	$29.66
INTERMEDIATE	$34.00
HYRAP INTERMEDIATE	$29.66
SURFACE	$38.19
HYRAP SURFACE	$33.66

In summary, the HyRAP mix designs save the customer more than 9% in cost on the base layer, over 12% on the intermediate layer, and over 11% on the surface layer of asphalt. These differences can be accounted for in the action of reclaiming the existing asphalt and processing it for specific aggregate sizes.

Brooks Construction performed several projects over the summer of 2011 which can be used to create a comparison to fully show the financial advantage that HyRAP can offer to an owner. Table 5 shows the quantities in tonnage of each layer of asphalt and the costs associated with each. The cost comparisons show what the typical project cost vs. the HyRAP project cost.[1]

[1] P. Manoloff, (personal communication, October 5, 2011)

Table 5.

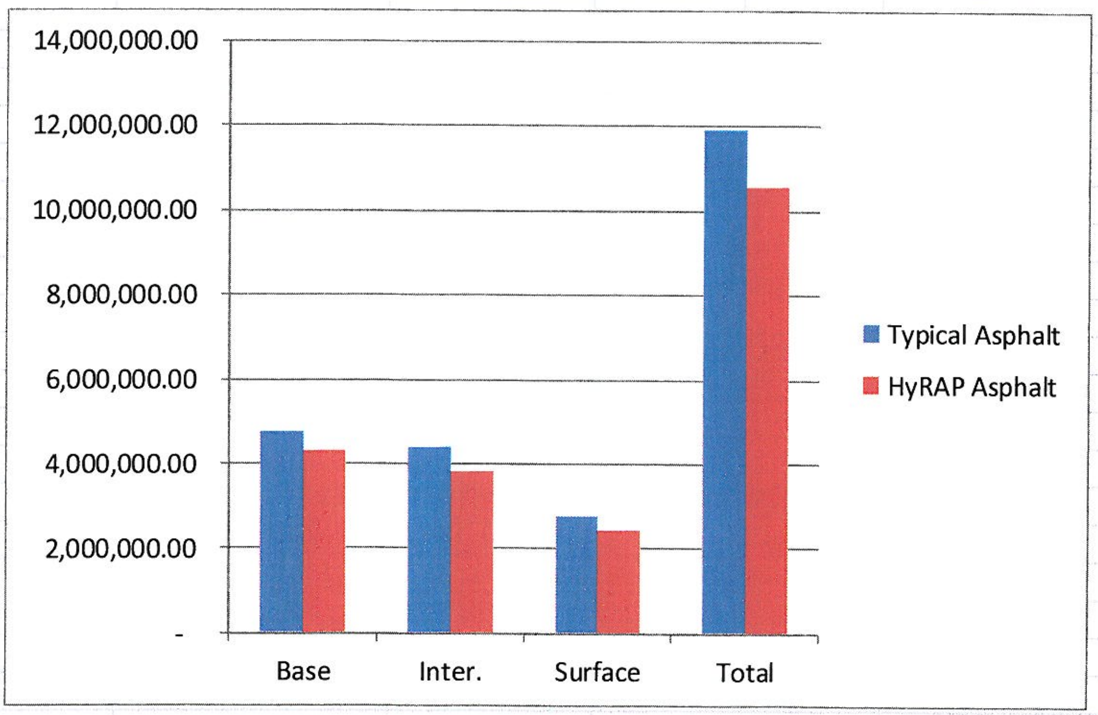
Hyrap Comparison of Top 13 Projects in 2011

PROJECT	MIX	QUANTITY	Typical	Hyrap	Typical Project Cost	Hyrap Project Cost	Total Project Savings	Total % Savings
	BASE	4,344.3200	32.67	29.66	141,932.27	128,862.94	(13,069.34)	9.21%
1	INTERMEDIATE	1,227.1800	34.00	29.66	41,723.58	36,401.10	(5,322.49)	12.76%
	SURFACE	2,378.1400	38.19	33.66	90,826.18	80,053.89	(10,772.29)	11.86%
					274,482.04	245,317.92	(29,164.12)	10.63%
	BASE	9,217.5300	32.67	29.66	301,143.79	273,414.02	(27,729.78)	9.21%
2	INTERMEDIATE	2,920.7400	34.00	29.66	99,303.88	86,636.14	(12,667.74)	12.76%
	SURFACE	1,711.4100	38.19	33.66	65,362.36	57,610.16	(7,752.20)	11.86%
					465,810.03	417,660.32	(48,149.71)	10.34%
	BASE	16,307.4800	32.67	29.66	532,777.91	483,718.91	(49,059.00)	9.21%
3	INTERMEDIATE	13,480.6300	34.00	29.66	458,335.53	399,867.77	(58,467.76)	12.76%
	SURFACE	3,983.3100	38.19	33.66	152,131.01	134,087.76	(18,043.26)	11.86%
					1,143,244.45	1,017,674.44	(125,570.01)	10.98%
	BASE	2,172.8800	32.67	29.66	70,989.66	64,452.83	(6,536.84)	9.21%
4	INTERMEDIATE	214.0200	34.00	29.66	7,276.59	6,348.35	(928.24)	12.76%
	SURFACE	55.5500	38.19	33.66	2,121.57	1,869.95	(251.63)	11.86%
					80,387.82	72,671.12	(7,716.70)	9.60%
	BASE	45,814.9800	32.67	29.66	1,496,810.62	1,358,982.04	(137,828.59)	9.21%
5	INTERMEDIATE	44,692.6100	34.00	29.66	1,519,529.23	1,325,689.86	(193,839.37)	12.76%
	SURFACE	8,690.6800	38.19	33.66	331,915.40	292,549.10	(39,366.30)	11.86%
					3,348,255.25	2,977,221.00	(371,034.25)	11.08%
	BASE	6,423.7500	32.67	29.66	209,868.85	190,543.81	(19,325.04)	9.21%
6	INTERMEDIATE	3,269.1300	34.00	29.66	111,148.99	96,970.23	(14,178.77)	12.76%
	SURFACE	923.0700	38.19	33.66	35,253.99	31,072.75	(4,181.24)	11.86%
					356,271.83	318,586.78	(37,685.05)	10.58%
	BASE	18,587.3500	32.67	29.66	607,263.02	551,345.32	(55,917.70)	9.21%
7	INTERMEDIATE	12,917.0800	34.00	29.66	439,175.08	383,151.53	(56,023.55)	12.76%
	SURFACE	5,788.4600	38.19	33.66	221,073.50	194,853.43	(26,220.07)	11.86%
					1,267,511.59	1,129,350.28	(138,161.32)	10.90%
	BASE	22,419.3600	32.67	29.66	732,457.73	665,011.91	(67,445.82)	9.21%
8	INTERMEDIATE	13,245.7800	34.00	29.66	450,350.74	392,901.56	(57,449.18)	12.76%
	SURFACE	104.9300	38.19	33.66	4,007.50	3,532.20	(475.30)	11.86%
					1,186,815.96	1,061,445.67	(125,370.29)	10.56%
	BASE	1,825.1200	32.67	29.66	59,628.07	54,137.43	(5,490.64)	9.21%
9	INTERMEDIATE	1,163.0400	34.00	29.66	39,542.85	34,498.55	(5,044.30)	12.76%
	SURFACE	22,478.6600	38.19	33.66	858,507.44	756,685.53	(101,821.90)	11.86%
					957,678.36	845,321.52	(112,356.85)	11.73%
	BASE	2,993.3900	32.67	29.66	97,796.35	88,791.12	(9,005.24)	9.21%
10	INTERMEDIATE	15,469.9500	34.00	29.66	525,971.55	458,875.77	(67,095.78)	12.76%
	SURFACE	8,559.7200	38.19	33.66	326,913.76	288,140.68	(38,773.08)	11.86%
					950,681.66	835,807.56	(114,874.10)	12.08%
	BASE	798.0300	32.67	29.66	26,072.25	23,671.48	(2,400.77)	9.21%
11	INTERMEDIATE	1,894.0600	34.00	29.66	64,397.21	56,182.36	(8,214.86)	12.76%
	SURFACE	7,667.7500	38.19	33.66	292,847.55	258,114.83	(34,732.72)	11.86%
					383,317.01	337,968.67	(45,348.34)	11.83%
	BASE	10,242.9900	32.67	29.66	334,646.36	303,831.62	(30,814.74)	9.21%
12	INTERMEDIATE	17,586.5000	34.00	29.66	597,933.32	521,657.71	(76,275.61)	12.76%
	SURFACE	9,663.2800	38.19	33.66	369,061.04	325,289.15	(43,771.90)	11.86%
					1,301,640.73	1,150,778.48	(150,862.25)	11.59%
	BASE	3725.06	32.67	29.66	121,700.57	110,494.20	(11,206.37)	9.21%
13	INTERMEDIATE	1033.05	34.00	29.66	35,123.25	30,642.74	(4,480.51)	12.76%
	SURFACE	724.26	38.19	33.66	27,661.02	24,380.33	(3,280.69)	11.86%
					184,484.84	165,517.27	(18,967.58)	10.28%
Grand Total					11,900,581.59	10,575,321.02	(1,325,260.57)	11.14%

The list in Table 5 contains quite the variety of projects based on the type and quantity of mix required. Each project required base, intermediate and surface asphalt mix. The higher the quantity of intermediate and/or surface asphalt mixes provides the greater percentage of savings. Overall, these projects created an average savings of 11.14%. Table 6, shown below, displays the cost comparison (in dollars) between each layer of asphalt contained in the thirteen projects shown in Table 5. It shows the base, intermediate and surface layer comparison and then a total cost comparison.

Table 6.

Cost Comparison Between Typical and HyRAP Asphalt.



The projects shown in Table 5 are actually state highway projects, and when analyzing these numbers one can see the advantages provided to the tax payer. In summarizing these state highway projects, the overall savings of the thirteen projects is more than $1.3 million. Keep in mind that thirteen projects is only a small sample of the overall work performed for the State Highway Department. The idea is that the tax payer has already paid for the material used to build that road. If HyRAP allows for the use of the same material to rebuild the road, then it's advantageous to both the tax payer and the state highway department to pursue the more cost effective method of building highways.

4.3 Mix Design Analysis Summary and Comparison

Lab tests and results show that the new HyRAP mixes meet the criteria for asphalt mix designs as required by state highway departments and industry standards. For privacy reasons, the projects shown in the tables will not be identified by customer or location; instead it will be identified by use.

Sample Projects One and Two, shown in Tables 6 and 7, show the extraction properties of a HyRAP half-inch intermediate mix. Both projects include "winter" properties for the intermediate mix. This means that the surface layer of asphalt will not be installed until next year. In Table 6 shown below, the HyRAP intermediate mix was designed for a commercial application, such as a parking lot. The data indicates that actual extraction percentages meet the commercial specifications, within tolerance levels.

Table 7. *Binder Mix Analysis Summary – Commercial Use*	Actual Percentages	Targeted Percentages
SAMPLE PROJECT ONE – ½" INTERMEDIATE MIX	Extraction - % PASSING SIEVE	Brooks Construction Extraction Commercial SPECS
1"		
¾"	100.00%	100.00%
½"	99.40%	90-100%
3/8"	95.67%	< 95%
#4	64.43%	
#8	36.40%	28-58%
#16	27.00%	
#30	21.33%	
#50	15.23%	
#100	10.37%	
#200	8.00%	2-10%
PG% (Asphalt Oil)	5.03%	5.00%

You may notice that on the 3/8" sieve, the HyRAP has a 95.67 passing percentage whereas the commercial specification calls it to be less than 95%. In this case, Brooks Construction decided to adjust the mix design and increase the amount of larger aggregate since it will set exposed over the winter.

In another intermediate mix designed for private use, Table 7 compares the actual percentages of the HyRAP mix to the industry specs for private customer use. Private use includes projects such as large driveways and private roads and parking lots. One additional item to notice on these tables is the PG%, or the liquid asphalt percentage. Generally, commercial and highway specifications call for a "four-tenths" tolerance. This means that four tenths of a percentage point above and below the designated specification is allowed. For private use, this increases to seven-tenths of a percentage.[2]

[2] P. Sievers, (personal communication, October 28, 2011)

Table 8. *Binder Mix Analysis Summary – Private Use*	Actual Percentages	Targeted Percentages
SAMPLE PROJECT TWO - 1/2" INTERMEDIATE MIX	Extraction - % PASSING SIEVE	Brooks Construction Extraction Private Specs
1"		
3/4"	100.00%	100.00%
1/2"	99.60%	90-100%
3/8"	94.20%	< 95%
#4	58.10%	
#8	31.70%	28-58%
#16	24.10%	
#30	19.20%	
#50	14.00%	
#100	9.80%	
#200	7.70%	2-10%
PG% (Asphalt Oil)	4.75%	5.00%

Over several years of company research and quality control, Brooks Construction has come up with a guideline of extraction specifications that they depend on to provide a quality product to their private and commercial customers. This is where the specifications in Tables 6 and 7 come from.

Surface mixes are perhaps the most tricky when designing with increased recycled content. Extra care must be taken to make sure the mix contents remain steady and within specifications because this layer of asphalt is the layer that will be seen after a project is completed. Using recycled and processed aggregates makes this task more difficult, but it can be accomplished. Table 8 shows a HyRAP surface mix used in a commercial application, but it is compared to the Indiana Department of Transportation specifications for use on public roads and highways.

Table 9. *Surface Mix Analysis Summary - Commercial Use*		
SAMPLE PROJECT THREE - SURFACE MIX	Actual Extraction - % PASSING SIEVE	Targeted Percentages Extraction INDOT SPECS
1"		
3/4"	100.00%	
1/2"	98.50%	100.00%
3/8"	91.40%	90-100%
#4	65.90%	
#8	44.10%	32-67%
#16	33.80%	
#30	25.50%	
#50	17.50%	
#100	11.00%	
#200	8.30%	2-10%
PG% (Asphalt Oil)	5.41%	5.40%

Table 10. *Surface Mix Analysis Summary – Private Use*		
SAMPLE PROJECT FOUR - SURFACE MIX	Actual Extraction - % PASSING SIEVE	Targeted Percentages Extraction Private SPECS
1"		
3/4"	100.00%	
1/2"	99.50%	97-100%
3/8"	96.00%	90-100%
#4	63.70%	
#8	35.80%	32-67%
#16	26.90%	
#30	21.10%	
#50	15.00%	
#100	10.20%	
#200	7.90%	2-10%
PG% (Asphalt Oil)	5.01%	5.20%

Table 9 shows a HyRAP surface mix used in a private application and is then compared to the industry specs for private use. As stated before during the intermediate mix design comparisons, the PG% has specific tolerance levels for highway, commercial and private uses. Highway and commercial work allows for a "four-tenths" of a percentage above and below the specified target percentage. Private work allows for a "seven-tenths" of a percentage above and below the specified target percentage.

5. Conclusion

Through this method of data collection and analysis, a conclusion can be determined from the results. Using the technology available, increasing the recycled content of asphalt and creating a usable mix design has proven achievable. Through the analysis, the performance theory was tested and the economic impact estimated in order to compare the use of an asphalt mix design containing normal materials against those containing a higher recycled content. The cost comparison between HyRAP and conventional asphalt mixes unveiled the potential for huge savings to the customers of Brooks Construction. Private and commercial customers have already begun to enjoy these savings. The mix analysis has shown that the HyRAP mix designs meet the specifications needed in order to produce a quality product as compared to conventional mixes.

Undoubtedly, the technology and external materials will improve over the years making the production, application and performance of a high-RAP mix even better. The Indiana Department of Transportation has shown interest in the HyRAP product, but has been slow to embrace the idea that increasing the percentage of recycled product in current asphalt mixes can result in a sustainable product. It will certainly take additional research, such as that performed by Stantec Consulting for CALTRANS, of the performance of HyRAP for INDOT to begin trying the product on its highways.

References

Asphalt Pavement Association of California. (2010). *Benefits of asphalt.* Retrieved from http://www.apaca.org/asphalt/.

Asphalt Pavement Association of Indiana. (2009). *Reclaimed asphalt pavement.* Retrieved from http://www.apai.org.

Asphalt Pavement Alliance. (2010). *Asphalt, the sustainable pavement.* Retrieved from http://www.asphaltroads.org/Environment.

Banasiak, David. (1997). RAP alters asphalt plant design. *Roads and bridges, 35* (1), 26-8.

Bernard, Douglas, A. (1985). Research pays off – asphalt pavement recycling. *TRNews,vol* (8), 22-23.

Brown, Daniel, C. (2005). Asphalt recycling gains momentum. *Public works, 136* (3), 34-7.

Brown, Daniel, C. (2009). A second chance. *Public works, 140 (4)*, 42-44.

California Department of Transportation (CALTRANS). (2011). *California Paving Asphalt Price Index*. Retrieved from http://www.dot.ca.gov/hq/esc/oe/asphalt_index/astable.html.

Georgia Asphalt Pavement Association. (2010). *Asphalt pavement recycling.* Retrieved from http://www.gahotmix.com/asphalt-recycling.aspx.

Federal Highway Administration (FHWA). (1997). *Pavement Recycling Guidelines for State and Local Governments Participant's Reference Book.* (Publication No. FHWA-SA-98-042). Retrieved from http://www.fhwa.dot.gov/pavement/recycling/98042/index.cfm.

Harris, Stephanie. (2007). Reuse the abused. *Roads and bridges, 45* (5), Retrieved from http://www.roadsbridges.com/Reuse-the-Abused-article8159.

Huh, J.D., Park, J.Y. (2009). A new technology of recycling 100% reclaimed asphalt pavements. *Journal of testing and evaluation, 37* (5), 1-4.

Indiana Department of Transportation (INDOT). (2011). *PG 64-22 Average Monthly Price.* Retrieved from http://www.in.gov/indot/files/PGAsphaltBinderIndex.pdf.

Indiana Department of Transportation (INDOT). (2011). *Standard Specifications 2012.* Retrieved from http://www.in.gov/dot/div/contracts/standards/book/sep11/sep.htm.

Johnson, Joan. (2008). recycled asphalt: the green roadway in the paving industry. *Colorado springs business journal.* Retrieved from http://findarticles.com/p/articles/mi_qn4190/is_20080418/ai_n27515757.

References

Lewis, Michael. (1995). *Manufacturing from recyclables: 24 case studies of successful recycling enterprises*. Washington, D.C. Diane Publishing Company.

Los Angeles Bureau of Street Services. (2011). *Resurfacing and Reconstruction*. Retrieved from http://www.ci.la.ca.us/boss/Resurfacing/Green.html.

Madison, Adam. (2009). The economy: crushed and recycled. *Rock products, 112* (10), 30.

Martin, Hugo. (1992, November 2). Facility allows city to recycle its roadways. *Los Angeles Times*.

Markley, Rick. (2010). Recycling aggregate. *Rock products, 113* (5), 26-7.

National Environmental Technology Applications Corporation (NETAC). (1992). *Microwave Process for Asphalt Pavement Recycling*. Environment & Energy Management EPRI Industrial Program. Retrieved from http://www.p2pays.org/ref/10/09079.

National Highway Cooperative Research Program. (2001). *Recommended use of reclaimed asphalt pavement in the superpave mix design method: technician's manual*. (NHCRP Report 452). Washington, DC: National Academy Press.

Newcomb, David. (2006). Save asphalt – up the rap. *Public works,* 137 (7), 70.

Newcomb, David. (2008). *Reclaimed asphalt pavement NAPA special report SR-191*. Retrieved from http://www.hotmix.org/reports/sr-191.

Robinette, Chris. (2010). Light on its foot. *Roads and bridges, 48* (5), 3.

Ryan, Neil. (2010). Y=FDR. *Roads and bridges, 48* (2), 3.

Tao, M., Zhang, Z., & Wu, Z. (2008). Simple procedure to assess performance and cost benefits of using recycled materials in pavement construction. *Journal of materials in civil engineering, 20* (11), 8.

Parks, Alexis. (1993). Repaving, reworking, recycling. *American city & county. 10* (108), 60-71.

Pereira, P. A. A., Oliveira, J. R. M., Picado-Santos, L. G. (2004). Mechanical characterization of hot mix recycled materials. *International journal of pavement engineering, 5* (4), 10.

Wilson, Bill. (2009). A good rap. *Roads and bridges, 47,* (2), 31-33, 64.

Wu, Corinna. (1998). Recycling the road. *Science news, 153* (4), 61.

References

Zaghloul, S., Holland, T.J., & Peng, P.E. (2007). Reporting live: recycling/reclaiming. *Roads and bridges, 45* (5), 50-4.

Zeyher, Allen. (2009). Warm mix rap – pushing limits. *Roads and bridges, 47* (10), 34- 36.